Review Article

# Two decades of off-pump coronary artery bypass surgery: Harefield experience

**Shahzad G. Raja**

Department of Cardiac Surgery, Harefield Hospital, London, UK

*Correspondence to*: Shahzad G. Raja, BSc, MBBS (Hons), MRCS, FRCS (C-Th). Consultant Cardiac Surgeon, Department of Cardiac Surgery, Harefield Hospital, London, UK. Email: drrajashahzad@hotmail.com.

**Abstract:** The morbidity and mortality associated with conventional coronary artery bypass grafting (CABG) attributed to invasiveness of cardiopulmonary bypass (CPB) has been well documented. Recognition of this invasiveness with a focus centered on abolishing, or at least reducing the CPB associated morbidity and mortality led to the resurgence of off-pump coronary artery bypass (OPCAB) surgery nearly two decades ago. At about the same time, OPCAB was adopted at Harefield hospital partly as an institutional drive to promote innovation and partly as a strategy to improve outcomes. What was deemed as a challenging technique initially and practiced by a single surgeon has now become a valid substitute to conventional CABG for achieving complete myocardial revascularization. This strategy now accounts for more than 50% of all coronary artery surgery operations at Harefield hospital and is systematically used to treat all coronary anatomies; achieve complete revascularization by accessing all territories subtended by main coronary arteries; and accomplish equivalent quality grafts without restriction in vascular conduit usage. This review article provides an overview of the evolution of OPCAB surgery at an institution with a well-established OPCAB program confirming that as surgeons' experience matures, OPCAB surgery permits safe and effective total myocardial revascularization in virtually all patients with multivessel coronary artery disease.

**Keywords:** Coronary artery bypass grafting (CABG); cardiopulmonary bypass (CPB); learning curve; myocardial revascularization; off-pump coronary artery bypass grafting

Submitted Aug 18, 2016. Accepted for publication Sep 19, 2016.
doi: 10.21037/jtd.2016.10.103
**View this article at:** http://dx.doi.org/10.21037/jtd.2016.10.103

The mortality and significant morbidity of conventional coronary artery bypass grafting (CABG) is largely attributed to the use of cardiopulmonary bypass (CPB) (1). Systemic inflammation, global ischemia due to cardiac arrest, hypothermia, and manipulation of the aorta are well-established contributors to CPB-associated organ dysfunction (2). Recognition of these aspects of CPB led to the resurgence of off-pump coronary artery bypass (OPCAB) surgery nearly two decades ago (3). Encouraged by the early published outcomes and an institutional drive to promote innovation, OPCAB was adopted as a strategy for selective single- or two-vessel coronary bypass grafting at Harefield hospital in September 1996. Over the next 20 years, technological advances and adherence to a strict policy of regular evaluation of safety and efficacy of the technique resulted in the establishment of a robust OPCAB program for multivessel revascularization that is recognized both nationally as well as internationally for its outcomes. This review article provides an overview of the evolution of OPCAB surgery at an institution with a well-established OPCAB program focusing predominantly on key publications highlighting major developments. The evolution for descriptive purposes is divided into three phases, namely initial phase (1996 to 2002), consolidation phase (2003 to 2010), and maintenance phase (2011 to date).

## Initial phase (1996 to 2002)

Beating heart coronary surgery was introduced at Harefield

hospital in September 1996. For the first 3 years, only 3–5% of the CABG procedures were done off-pump. These were mostly single vessel minimally invasive direct coronary artery bypass procedures and infrequently two-vessel bypass procedures excluding the circumflex territory. After evaluating the literature on evolution and outcomes of OPCAB operations, visiting units and deliberations with colleagues at units practicing OPCAB operations, as well as after attending proctored training course, one of the surgeons completely switched from our routine practice of using CPB to regular multivessel OPCAB operations in July 1999 (4). After the conversion date, our surgical plan for all CABG procedures was to start the operation with a strategy to perform OPCAB, yet retain the same revascularization plan that we would normally follow if the procedure were performed in a conventional manner with CPB. All patients referred for isolated CABG were accepted for OPCAB operations without any selection criteria.

During this initial phase our choice of conduits remained consistent with our pre-OPCAB practice (5). The left internal thoracic artery as a pedicle graft was our preferred choice for the left anterior descending artery and the right internal thoracic artery routed through the transverse sinus was preferentially used for grafting the circumflex artery. When the right internal thoracic artery was of inadequate length it was used as a free or composite graft. In case of previous radiotherapy, severe obstructive airway disease, corticosteroid use or some insulin-dependent diabetics, contraindicating the use of bilateral internal thoracic arteries, the radial artery was preferentially used for revascularizing the circumflex territory. Otherwise the radial artery was utilized for grafting targets in the right coronary territory. Sequential grafts or saphenous veins were used as supplemental grafts when needed. The saphenous vein was also used if multiple arterial grafting was considered to be of limited benefit such as in the presence of severe distal coronary artery disease, advanced age, and disease conditions limiting life-expectancy.

General anesthetic technique consisted of low-intermediate dose opioid (usually fentanyl 8 to 15 $\mu g \cdot kg^{-1}$) and a propofol infusion (3 mg/kg per hour). Thoracic epidural blockade with bupivicaine and fentanyl was selectively used and maintained for 24 to 72 hours postoperatively (depending on preference of the anesthetist) (4). Standard intraoperative monitoring techniques were utilized. Transesophageal echocardiography was used for additional monitoring. Pulmonary artery flotation catheters were placed infrequently. Excessive heat loss during the procedure was prevented by the use of heating mattresses and a warm airflow sheet on the lower half of the body. Heparin in a dose of 150 units per kg was used to achieve anticoagulation. The activated clotting time was maintained at more than 250 seconds. Heparin was neutralized with protamine at completion of the procedure. Blood pressure was optimized during the procedure by means of cardiac maneuvering and selective use of vasoconstrictors. Other interventions to improve cardiac output, such as elevation of feet and cardiac pacing, were used as appropriate. Perfusionist standby was available for all OPCAB cases. Patients who were converted at any stage during the operation (including prior to the onset of grafting) were considered conversions (4). Persistent hypotension (mean arterial blood pressure less than 50 mmHg) i.e., nonresponsive to pharmacological and surgical maneuvers and worsening arrhythmias secondary to ischemia were the criteria for intraoperative conversion to CPB (4).

### *Outcomes from the initial phase*

Outcomes of our first 285 OPCAB cases using the Octopus System (Medtronic Inc., Minneapolis, MN, USA) were published in *EJCTS* in 2002 (4). This relatively small patient population representing our institutional as well as an individual surgeon's "learning curve" with the OPCAB technique showed that complete shift from conventional CABG using CPB to the routine adoption of OPCAB operations can be achieved without changing the revascularization practice. The morbidity rates were similar to those in the pre-OPCAB era confirming that there were no clear detrimental effects to patients. We retained our preferred operative strategy of arterial revascularization. Arterial conduits were used, for performing 98% of the left anterior descending artery and 78% of circumflex grafts, maintaining our preference for left-sided arterial grafting. In our target group for arterial grafting, comprising of patients less than 70 years old, 80% had total arterial revascularization. Our conversion rate was low (3%). As part of our quality control during this initial phase, 6 of the first 15 OPCAB patients had early angiograms that were unremarkable. Our early experience suggested that with appropriate training, the learning curve for OPCAB can be negotiated without significant risk or modification in practice and OPCAB operations are feasible without patient selection, additional risk to patients, or compromising the number or type of grafts performed (particularly a preference for arterial grafting) (4).

 

## Consolidation phase (2003 to 2010)

Encouraged by our initial experience, OPCAB surgery gained wide acceptance as a valid alternative to conventional CABG in our institution during the consolidation phase. This progression to systematic OPCAB multivessel revascularizations was fuelled by the refinement of stabilization technology enabling easy surgical access to all coronary territories, the evolution of a surgical technique permitting hemodynamically stable heart manipulations and circumflex exposure, encouraging early angiographies demonstrating excellent graft patency, and constantly improving outcomes.

### *Outcomes from the consolidation phase*

The consolidation phase was marked by a thorough analysis of all aspects of the OPCAB experience. We evaluated the initial experience with OPCAB surgery in the United Kingdom and demonstrated a lowering in risk stratified morbidity and mortality at a multicentre level (6). Our data on specific groups of patients, including elderly patients (7), high risk patients (8), and patients with ischemic left ventricular dysfunction (9) as well as outcomes of OPCAB sequential grafting (10) were also retrospectively analysed and published.

Having gone through the learning curve and realizing that in the era of evidence-based medicine any new surgical technique must be subjected to the rigors of a randomized trial for validation of safety and efficacy (11), a randomized controlled trial was designed to compare on-pump CABG and OPCAB surgery for clinical outcome, graft patency (evaluated by angiography), neurocognitive function, and health related quality of life (12). This trial showed that OPCAB surgery resulted in better clinical outcome, similar patency of grafts, shorter hospital stay, and improved neurocognitive function than patients who underwent conventional CABG using CPB. A further substudy reported that OPCAB surgery offered patients in this randomized trial similar health benefits to conventional CABG with CPB over a 6-month period, but at a significantly less cost (13).

During the consolidation phase, over 3,200 OPCAB operations were performed by four surgeons, three of whom performed 100% OPCAB surgery. There was a marked improvement in mortality for the overall CABG cohort with a trend toward a reduction in mortality in the OPCAB group. This occurred despite a higher EuroSCORE predicted risk of operative mortality in the OPCAB cohort compared with the conventional CABG cohort and the inclusion of patients for whom traditionally OPCAB grafting may have been deemed contraindicated such as those with intramyocardial or small coronary arteries, very large hearts, or decompensated heart failure.

## Maintenance phase (2011 to date)

Publication of the 1-year outcomes of ROOBY trial in 2012 raised serious concerns about patency of arterial and saphenous vein graft conduits and less effective revascularization after OPCAB than on-pump CABG (14). Opponents of OPCAB and skeptics, following the publication of this trial, questioned the impact of this poor graft patency and incomplete revascularization attributed to OPCAB on long-term survival (15). During this period of increasing skepticism about the negative impact of OPCAB, like most high-volume OPCAB centers, Harefield hospital has maintained the OPCAB practice. Despite a continued decline in CABG surgery, in line with the worldwide trend, over 1,700 OPCAB procedures (more than 50% of all isolated CABG) have been performed during the maintenance phase by the four OPCAB surgeons.

### *Outcomes from the maintenance phase*

The maintenance phase has focused on both short- as well as long-term outcomes of OPCAB surgery. We analyzed the 10-year outcomes of OPCAB multivessel arterial grafting (16) as well as sequential grafting (17). Outcomes of OPCAB surgery were also compared with those of on-pump CABG in octogenarians (18) and diabetics (19). Most importantly, we demonstrated that at long-term follow-up, OPCAB remains a safe and effective myocardial revascularization strategy with no adverse impact on survival or freedom from reintervention (20). Our published experience confirms that with the appropriate use of modern stabilizers, sophisticated heart positioning maneuvers, anesthetic advances, and adequate surgeon experience, similar completeness of revascularization and graft patency can be achieved, with OPCAB and conventional CABG, that translate into similar long-term survival and freedom from re-intervention (20).

## Conclusions

As a high-volume OPCAB surgery center, Harefield

 

hospital continues to offer OPCAB surgery as a valid alternative to conventional CABG. The surgeons, at this institution of national and international reputation, have developed a high level of expertise with this technique enabling them to offer this strategy to a large number of patients with increasing comorbidities and complexity of coronary lesions with excellent outcomes (3-13,16-20). More importantly, the OPCAB surgeons at Harefield hospital have not lost their focus in regard to the goals of surgical coronary revascularization. They strive to perform the most complete revascularization, a technically perfect anastomosis, using the best conduits with the minimal amount of hemodynamic instability. The procedure is performed under all circumstances and on all patients. Last but not the least, contrary to the widely held view, younger surgeons at Harefield hospital are trained to master this challenging technique as OPCAB surgery is perceived as an essential tool in the armamentarium of the coronary surgeons of the future.

## Acknowledgements

None.

## Footnote

*Conflicts of Interest:* The author has no conflicts of interest to declare.

## References

1. Raja SG, Berg GA. Impact of off-pump coronary artery bypass surgery on systemic inflammation: current best available evidence. J Card Surg 2007;22:445-55.
2. Raja SG, Dreyfus GD. Modulation of systemic inflammatory response after cardiac surgery. Asian Cardiovasc Thorac Ann 2005;13:382-95.
3. Mishra YK, Mishra M, Malhotra R, et al. Evolution of Off-Pump Coronary Artery Bypass Grafting over 15 Years: A Single-Institution Experience of 14,030 Cases. Innovations (Phila) 2005;1:88-91.
4. Anyanwu AC, Al-Ruzzeh S, George SJ, et al. Conversion to off-pump coronary bypass without increased morbidity or change in practice. Ann Thorac Surg 2002;73:798-802.
5. Anyanwu AC, Saeed I, Bustami M, et al. Does routine use of the radial artery increase complexity or morbidity of coronary bypass surgery? Ann Thorac Surg 2001;71:555-9; discussion 559-60.
6. Al-Ruzzeh S, Ambler G, Asimakopoulos G, et al. Off-Pump Coronary Artery Bypass (OPCAB) surgery reduces risk-stratified morbidity and mortality: a United Kingdom Multi-Center Comparative Analysis of Early Clinical Outcome. Circulation 2003;108 Suppl 1:II1-8.
7. Al-Ruzzeh S, George S, Yacoub M, et al. The clinical outcome of off-pump coronary artery bypass surgery in the elderly patients. Eur J Cardiothorac Surg 2001;20:1152-6.
8. Al-Ruzzeh S, Nakamura K, Athanasiou T, et al. Does off-pump coronary artery bypass (OPCAB) surgery improve the outcome in high-risk patients?: a comparative study of 1398 high-risk patients. Eur J Cardiothorac Surg 2003;23:50-5.
9. Al-Ruzzeh S, Athanasiou T, George S, et al. Is the use of cardiopulmonary bypass for multivessel coronary artery bypass surgery an independent predictor of operative mortality in patients with ischemic left ventricular dysfunction? Ann Thorac Surg 2003;76:444-51; discussion 451-2.
10. Al-Ruzzeh S, George S, Bustami M, et al. The early clinical and angiographic outcome of sequential coronary artery bypass grafting with the off-pump technique. J Thorac Cardiovasc Surg 2002;123:525-30.
11. Tan VK, Chow PK. An approach to the ethical evaluation of innovative surgical procedures. Ann Acad Med Singapore 2011;40:26-9.
12. Al-Ruzzeh S, George S, Bustami M, et al. Effect of off-pump coronary artery bypass surgery on clinical, angiographic, neurocognitive, and quality of life outcomes: randomised controlled trial. BMJ 2006;332:1365.
13. Al-Ruzzeh S, Epstein D, George S, et al. Economic evaluation of coronary artery bypass grafting surgery with and without cardiopulmonary bypass: cost-effectiveness and quality-adjusted life years in a randomized controlled trial. Artif Organs 2008;32:891-7.
14. Hattler B, Messenger JC, Shroyer AL, et al. Off-Pump coronary artery bypass surgery is associated with worse arterial and saphenous vein graft patency and less effective revascularization: Results from the Veterans Affairs Randomized On/Off Bypass (ROOBY) trial. Circulation 2012;125:2827-35.
15. Lazar HL. Should off-pump coronary artery bypass grafting be abandoned? Circulation 2013;128:406-13.
16. Raja SG, Navaratnarajah M, Kitchlu CS, et al. 10-year follow-up of off-pump multivessel coronary artery bypass grafting. Asian Cardiovasc Thorac Ann 2010;18:260-5.

 

17. Raja SG, Salhiyyah K, Navaratnarajah M, et al. Ten-year outcome analysis of off-pump sequential grafting: single surgeon, single center experience. Heart Surg Forum 2012;15:E136-42.
18. Raja SG, Shah J, Navaratnarajah M, et al. Outcomes and predictors of mortality and stroke after on-pump and off-pump coronary artery bypass surgery in octogenarians. Innovations (Phila) 2013;8:269-75.
19. Raja SG, Salhiyyah K, Rafiq MU, et al. In-hospital outcomes of pedicled bilateral internal mammary artery use in diabetic and nondiabetic patients undergoing off-pump coronary artery bypass grafting: single-surgeon, single-center experience. Heart Surg Forum 2013;16:E1-7.
20. Raja SG, Benedetto U, Chudasama D, et al. Long-term follow-up of off-pump and on-pump coronary artery bypass grafting. Innovations (Phila) 2014;9:122-9; discussion 129.

**Cite this article as:** Raja SG. Two decades of off-pump coronary artery bypass surgery: Harefield experience. J Thorac Dis 2016;8(Suppl 10):S824-S828. doi: 10.21037/jtd.2016.10.103

 